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Under-utilization of existing spectrum usage by licensed users is a well-known fundamental problem in current networks. A novel concept towards it's amelioration is that of cognitive radio networks that allow usage of such un- or under- used spectrum by unlicensed or secondary users, provided they do not interfere with the incumbent or primary users. Clearly, an enabler of such opportunistic use is fast and accurate determination of primary user (PUs) channel status (whether occupied or idle) by secondary networks, as well as accurate modeling of patterns of spectrum occupancy by PUs that are dynamic in both time and frequency. In our work, we explore various options - algorithmic and architectural - towards optimizing the (mean) time to detect channel status subject to accuracy constraints. Finally, we also explored information theoretic results for a new cognitive interference channel that allows for multiple co-located secondary networks.

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Sensing Aware Design Approaches for Airborne Networks

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1 Abstract

Under-utilization of existing spectrum usage by licensed users is a well-known fundamental problem in current networks. A novel concept towards it's amelioration is that of *cognitive radio networks* that allow usage of such un- or under- used spectrum by unlicensed or secondary users, provided they do not interfere with the incumbent or primary users. Clearly, an enabler of such opportunistic use is *fast and accurate* determination of primary user (PUs) channel status (whether occupied or idle) by secondary networks, as well as accurate modeling of patterns of spectrum occupancy by PUs that are dynamic in both time and frequency. In our work, we explore various options - algorithmic and architectural - towards optimizing the (mean) time to detect channel status subject to accuracy constraints. Finally, we also explored information theoretic results for a new cognitive interference channel that allows for multiple co-located secondary networks, a scenario that is increasingly anticipated in the future, as shown in Fig. 1. A summary of the main results obtained and contributions to state-of-art along these directions follows.

2 Summary of Technical Contributions

Theme 1: Models and Optimization for Smart Secondary Sensing

In this work, we first revisit conventional models for primary channel availability such as the random (i.i.d) model and a new correlated Markov model. Secondary users search for an available idle channel using either a pure random search or pure deterministic (n-step serial) search strategies. Using the mean time for detection of an idle channel as the performance metric, we highlight a key trade-off between the mean number of steps and the sensing time per step. Reduced sensing duration per step leads to lower detection probability (Pd) thereby increasing the average number of search steps required. This suggests the existence of an optimal sensing duration which minimizes the overall mean detection time.

Further, optimization of the mean detection time also has an additional degree of freedom that has hitherto not been explored - notably the detection threshold at each step [1,7]. We investigated the impact of *joint minimization* with respect to both the threshold and sensing duration at each step. We showed that the resulting non-convex problem is actually *biconvex* under practical conditions for which effective algorithms can be developed that yields reliable numerical procedures to solve the resulting optimization problem. The results show that the proposed approach can considerably improve the mean time to detect a spectrum hole, relative to optimizing with respect to only one variable (i.e. either the threshold or sensing duration).

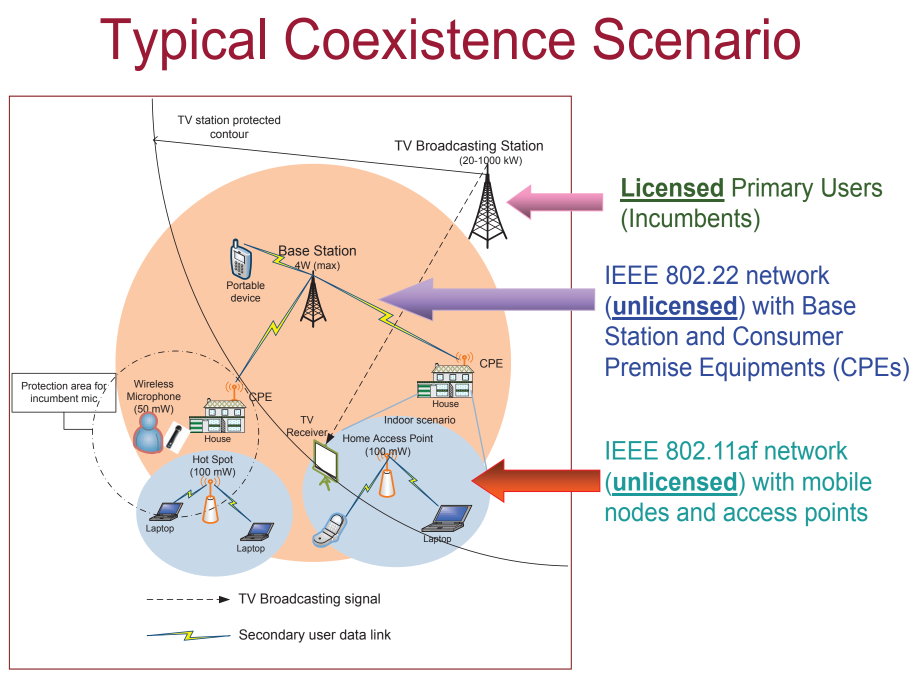

Figure 1: Heterogeneous Secondary Networks

Theme 2: Primary Channel Occupancy Models

Validated channel occupancy models for primary users that capture *variations* in time and frequency, are relatively sparse. Our contribution to this topic focused on modeling PU channel occupancy patterns over the 700 MHz spectrum based on a publicly available spectrum measurement data-set from Aachen, Germany. The primary contribution is to highlight that channel occupancy is *non identically* distributed, as can be expected over any sufficiently broad band - counter to the common i.i.d assumption in much of the literature. A Beta distribution was postulated since empirical data shows i) a small fraction of channels occupied with high probability, ii) another small fraction of channels occupied with low probability, and iii) the remaining (majority) occupied with moderate access probabilities. Our contribution [3, 4] resulted in the first validation of this model with appropriate Beta distribution parameters estimated from the data. Second, a computationally efficient model is developed by combining Poisson distribution for low and high occupancy probability regimes, with the usual Gaussian regime for the remainder.

Theme 3: Information theory based on a new Cognitive Interference Channel

Information theoretic analysis of cognitive radio networks has motivated *new* interference channel models, namely the *cognitive interference channel* that allows *one* secondary network. We introduce a new interference model [5] for *two* heterogeneous secondary networks (coexisting with primary network) as shown in Fig. 2 - scenarios that are expected to increasingly common in the future. This gives rise to the possibility of new information regimes based on different modes of sharing of available side information among the secondary networks. For example, we explore a scenario whereby users in the second cognitive network possess full knowledge of the transmitted symbols by the primary user *and* users from the first secondary network. We explore the achievable transmission rates for this regime when all users employ Gaussian codebooks by introducing a new auxiliary variable for each secondary user, a generalization of the approach proposed by Costa [1]

[1] M. Costa, "Writing on Dirty Paper," IEEE Trans. IT, 1983.

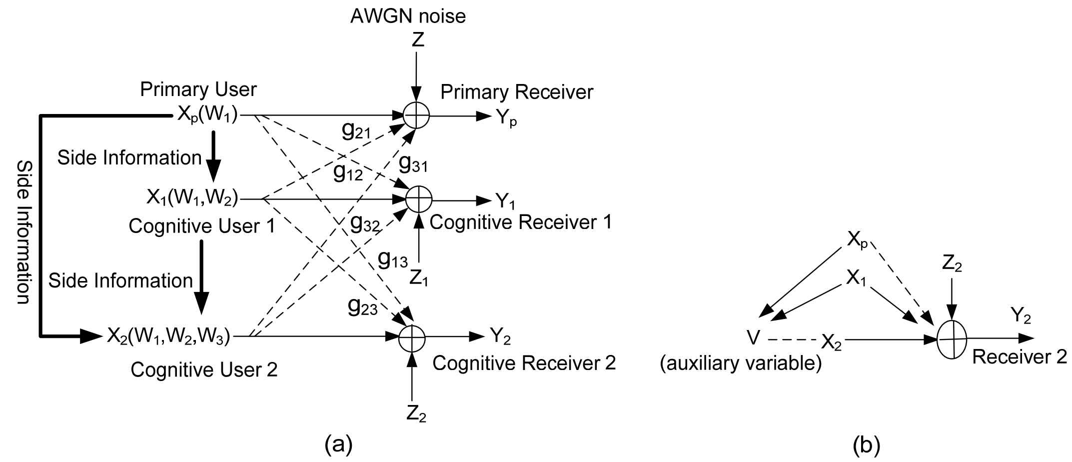

Figure 2: Heterogeneous Cognitive Interference Channel

in determining the capacity of such a channel. We show that the achievable transmission rates in this case is substantially higher than that of Costa's achievable rates using dirty paper coding in the low and strong interference regions.

3 Personnel Supported

The funding was used to support Dr. Ling Luo (PhD student) in 2009-10 and Dr. Chittabrata Ghosh, a post-doctoral scholar for 2010-2011.

4 Publications

1. L. Luo, C. Ghosh and S. Roy, Joint Optimization of Spectrum Sensing for Cognitive Radio Networks, Proc. IEEE Globecom 2010, Miami, FL, Dec. 2010.

2. C. Ghosh, S. Roy, and D. Cavalcanti, "Coexistence in Cognitive Wireless Heterogeneous Networks," IEEE Wireless Communication Magazine, October 2011.

3. C. Ghosh, S. Roy, M. B. Rao, and D. P. Agrawal, "Spectrum Occupancy Modeling and Validation using Real-time Measurements," 2nd ACM Sigmobile Workshop on Cognitive Wireless Networking, CoRoNet'10, September 20, 2010.

4. C. Ghosh, S. Roy and M. B. Rao, "Spectrum Availability Modeling and Validation using Real-time Measurements," submitted to IEEE J. Selected Areas Commn., Jun. 2011.

5. C. Ghosh and S. Roy, "Achievable Transmission Rates in a Heterogeneous Cognitive Networks," submitted to IEEE Transactions on Information Theory, March 2011.

6. L. Luo and S. Roy, Modeling and Analysis of Detection Time Trade-offs for Channel Searching in Cognitive Radio Networks, IET Communications, 2012 (to appear).

7. L. Luo and S. Roy, Efficient Spectrum Sensing for Cognitive Radio Networks via Joint Optimization of Sensing Threshold and Duration, IEEE Trans Commn., 2012 (accepted).